# Display device

The invention relates to a display device comprising a liquid crystal material between a first substrate provided with row or selection electrodes and a second substrate provided with column or data electrodes, in which overlapping parts of the row and column electrodes define pixels, and drive means for driving the column electrodes in conformity with an image to be displayed. Such display devices are used in, for example portable apparatuses such as laptop computers, notebook computers and telephones.

Passive matrix displays of this type are generally known. In such a display *m* is the number of rows to be maximally multiplexed with a maximum contrast determined by the threshold voltage $V_{th}$ and the saturation voltage $V_{sat}$ of the liquid crystal material. As described in the Alt & Pleshko analysis (IEEE Trans. El. Dev., Vol ED-21, No. 2, Febr. 1974, pp. 146-155), this maximum number of rows is equal to:

$$m = \frac{\left(V_{th}^2 + V_{sat}^2\right)^2}{\left(V_{sat}^2 - V_{th}^2\right)^2}$$

In an article by T.N. Ruckmongathan et al. "A New Addressing Technique for Fast Responding STN LCDs", Japan Display 92, pp. 65-68, a group of *L* rows is driven with mutually orthogonal signals. Since a set of orthogonal signals, such as Walsh functions, consists of a number of functions which is a power of 2, hence $2^S$, *L* is preferably chosen to be as equal as possible thereto, hence generally $L = 2^S$, or $L = 2^S-1$. The orthogonal row signals $F_i(t)$ are preferably square-shaped and consist of the voltages +F and -F, while the row voltage is equal to zero outside the selection period. The elementary voltage pulses of which the orthogonal signals are composed, are regularly distributed in the field period. Thus, the pixels are then excited $2^S$ or $(2^S-1)$ times per field period with regular intervals instead of once per field period (Multiple row addressing).

Notably in applications in display devices built into portable apparatuses (mobile telephone, laptop computers) the aim is not only to drive these apparatuses with a

minimal energy but also to introduce further functions such as sensing and activation of the display device (singing display).

It is an object of the invention to provide a display device of the type described above in which a drive voltage is chosen to be as favorable as possible and in which these functions can be combined.

To this end the display device comprises drive means for driving the column electrodes and the row electrodes by which drive means the column electrodes are selected during a selection time $t_l$ and further drive means for driving row electrodes or column electrodes in conformity with a further non-image application during a period $t_{app}$ , in which the multiplexibility $m$ of the liquid crystal is larger than $(N. t_l + t_{app})/ t_l$.

One embodiment comprises drive means for driving the column electrodes and drive means for driving M row electrodes in conformity with a further non-image application, in which the multiplexibility $m$ of the liquid crystal is larger than (M/n + N) in which n is the number of simultaneously driven row electrodes during said further non-image application.

Especially when the driving signals for said M row electrodes and the corresponding column signals during selection of said M row electrodes (or the extra drive means in general) result in a zero RMS voltage the image displayed is not influenced by the other functions.

These and other aspects invention will now be elucidated with reference to some non-restricting embodiments and the drawing in which

Fig. 1 shows diagrammatically a display device in which the invention is used,

Fig. 2 shows a transmission/voltage characteristic curve of a liquid crystal material to be used in the device of Figure 1,

Figure 3 shows the multiplexibility as a function of $V_{probe}$ for a display with a certain liquid crystal material, while.

Figure 4 shows the multiplexibility as a function of the probing time and

Figures 5 - 8 show different examples of driving schemes for a display device in which the invention is used.

Fig. 1 shows a display device with a matrix 1 of pixels 10 at the area of crossings of rows 2 and columns 3 which are provided as row electrodes 2' and column electrodes 3' on facing surfaces of substrates 4, 5, as can be seen in the cross-section shown in the matrix 1. The liquid crystal material 6 is present between the substrates. For the sake of simplicity, other elements, such as orientation layers, polarizers, etc. are omitted in the cross-section.

The row electrodes are (consecutively) selected by means of a row driver 7, while the column electrodes are provided with data via a data register 8. To this end, incoming data 12 and selection signals 14 are first processed, if necessary, in a (software) processor 15. Mutual synchronization between the row driver 7 and the data register 8 occurs via control lines 9 in the synchronization unit 13. The processor 15 also controls via control lines 16 switch control circuits 17, 18 and any further control circuit 19, dependent on an application as defined by block 20.

The row driver 7 in the situation shown provides selection signals having amplitude $V_s$ to the rows 2. To this end switches 21 controlled by control circuit 17 via control lines 23 connect outputs of row driver 7 to the rows 2. At the same time the column driver 8 provides data signals having amplitude $V_d$ to the columns 3. To this end switches 22 controlled by control circuit 18 via control lines 24 connect outputs of row driver 7 to the columns 3.

As discussed in the Alt & Pleshko analysis (IEEE Trans. El. Dev., Vol ED-21, No. 2, Febr. 1974, pp. 146-155) for a passive driven (S(uper)) T(wisted) N(ematic) L(iquid) C(rystal) D(isplay), the root-mean-square pixel voltage has to be higher than the saturation voltage ($V_{sat}$) for dark pixels and lower than the threshold voltage ($V_{th}$) for bright pixels for a normally white display (or vice versa for a normally black display), see Figure 2 which shows a transmission/voltage characteristic curve of a liquid crystal material to be used in such a normally white display. The root-mean-square average voltage over a frame time determines the pixel voltage. For a display with N lines, driven with a row voltage $V_r$ and a column voltage $\pm V_c$, the average square pixel voltage is:

$$\overline{V}_{pix}^2 = \frac{1}{N}\left((N-1)V_c^2 + (V_c \pm V_r)^2\right)$$

By solving the equations for $V_{pix} = V_{th}$ and $V_{pix} = V_{sat}$, expressions are found for $V_c$ and $V_r$ and for the multiplexibility or the maximum number of lines which can be addressed viz.:

$$N_{\max} = \frac{\left(V_{th}^2 + V_{sat}^2\right)^2}{\left(V_{sat}^2 - V_{th}^2\right)^2} \qquad (1)$$

According to the invention for a further function, indicated by block 25 in Figure 1 different voltages can be applied via the switches 21 controlled by control circuit 17 via control lines 23 to electrodes 2. The further function may introduce voltages related to said further function (e.g. a probe function or activation of the full display device into vibration). If necessary different voltages can be applied simultaneously (either directly or by control of control circuit 19) via the switches 22, controlled by control circuit 18 via control lines 24, to electrodes 3. On the other hand the voltages for a probe function or activation of the full display may be applied to electrodes 3 only.

When using probe signals or activating signals only a part of the frame time is used for addressing the display. For a display with N lines and a line time of $t_{row}$, the total frame time is N $t_{row}$. When probing signals are present, this time will be (N+M) $t_{row}$, where it is assumed that the time needed for probing is M.$t_{row}$. (M can be understood as the number of sacrificed rows, in this case the number of rows used for probing). During the probing, each pixel senses an average square voltage $V_{probe}^2$. The average pixel voltage will now be:

$$\overline{V}_{pix}^2 = \tfrac{1}{N+M}\left((N-1)V_c^2 + (V_c \pm V_r)^2 + MV_{probe}^2\right)$$

Solving this for $V_{pix} = V_{sat}$ and $V_{pix} = V_{th}$, the row and column voltages are:

$$V_c = \tfrac{1}{2}\sqrt{\tfrac{1}{N}\left(\begin{array}{l} -2MV_{probe}^2 + (M+N)(V_{sat}^2 + V_{th}^2) - \\ \sqrt{\left(-N(M+N)^2(V_{sat}^2 - V_{th}^2)^2 + (-2MV_{probe}^2 + (M+N)(V_{sat}^2 + V_{th}^2))^2\right)} \end{array}\right)} \qquad (2)$$

$$V_r = -\left((M+N)(V_{sat}^2 - V_{th}^2)\right) \Big/ \left(2\sqrt{\tfrac{1}{N}\left(\begin{array}{l} -2MV_{probe}^2 \\ +(M+N)(V_{sat}^2 + V_{th}^2) - \sqrt{\left(\begin{array}{l} -N(M+N)^2(V_{sat}^2 + V_{th}^2)^2 \\ +\left(-2MV_{probe}^2 + (M+N)^2(V_{sat}^2 + V_{th}^2)\right)^2 \end{array}\right)} \end{array}\right)}\right)$$

The row voltages and column voltages in the absence of probing signals can be found by putting M=0 and are equal to those of the Alt & Pleshko analysis. The multiplexibility can be found by solving:

$$\left(-N(M+N)^2(V_{sat}^2-V_{th}^2)^2+(-2MV_{probe}^2+(M+N)(V_{sat}^2+V_{th}^2))^2\right)=0$$

Figure 3 shows the multiplexibility as a function of $V_{probe}$ for a S(uper) T(wisted) N(ematic) L(iquid) C(rystal) D(isplay) with a multiplexibility of the liquid crystal material of 219 and a $V_{th}$=1V, $V_{sat}$=1.07V. It shows that for a probing signal of 1V, a display with 194 lines can be driven. Figure 4 shows the multiplexibility as a function of the probing time (expressed in M, the number of line addressing times needed for probing) for a $V_{probe}$=1V. So if 20 line times are needed for the probing signals a display with 180 lines can be driven.

In the calculations $V_{probe}^2$, the root-mean-square average value of the probing voltage at the picture element, is used and M, which means that M.$t_{row}$ is a measure of the total amount of time spent for the probing during one frame. The probing may be spread over the frame time (e.g. probe every line immediately before or after it has been addressed) or in a block at the end of every frame.

The first possibility is shown in Figure 5 in which during subsequent time periods $t_w$ a picture element is selected (a signal $V_s$ is applied to a row electrode, while a signal $\pm V_d$ is applied to a column electrode), while immediately after selection of row i (i = 1,2,3 in this example) a signal $V_{touch}$ is applied to column electrode i to electrodes 3,while the electrodes 2 stay at 0V. The probing of a touch action is performed by ways per se known in the art.

Figure 6 shows an alternative driving schema in which touch detection occurs after writing N lines. M lines are selected (during a line selection time in this example) for probing of the touchingaction. . Now the probing signal $V_{touch}$ is applied to the row electrodes. The total time for probing is M.$t_{row}$ , which in certain applications may be shortened by probing two or more lines simultaneously.

Figure 7 shows an alternative to the driving signals of Figure 5. Now immediately after selection of row i (i = 1,2,3 in this example) a signal $V_{touch}$ is applied to row electrode i while the electrodes 3 stay at 0V.

In another embodiment the row driver 7 comprises a row function generator implemented, for example as a ROM, for generating orthogonal signals $F_i(t)$ for driving the rows 2. Similarly as described in the article by Scheffer and Clifton, mentioned in the introductory part, row vectors are defined during each elementary time interval, which row

vectors drive a group of $p$ rows via the row driver. The row vectors are written into a row function register while information to be displayed is stored in an buffer memory and read as information vectors per elementary unit of time. Signals for the column electrodes 3 are obtained by multiplying the then valid values of the row vector and the information vector by each other during each elementary unit of time and by subsequently adding the obtained products. In this case, $p$ rows are always driven simultaneously, in which $p$< M.

This method of driving does not change the multiplexibility $m$ of the liquid crystal material. Adding the probing signals alters the row and column voltages needed for multiple row addressing in a different way than for single row addressing as described above, but the dependence of N on M and $V_{probe}$ is the same as shown in Figure 3.

For a display of N lines driven with p lines at a time, the row signals are given by the orthogonal functions $F_i$ (0<i<=p) with:

$$\frac{1}{T}\int_0^T F_i F_j \, dt = 0 \quad ; i \neq j$$
$$= F^2 \, ; i = j$$

The column signal of column j is given by:

$$G_j(t) = \frac{1}{D}\sum_{i=1}^{p} a_{ij} F_i(t)$$

With $a_{ij}$=1 for a dark pixel and $a_{ij}$=-1 for a bright pixel. The row and column signals are now defined by F and D:

$$F = \frac{1}{2\sqrt{p}}\sqrt{\begin{array}{l}-2MV_{probe}^2 + (M+N)(V_{sat}^2 + V_{th}^2) \\ -\frac{1}{2}\sqrt{-4N(M+N)^2(V_{sat}^2 - V_{th}^2)^2 + \left(-4MV_{probe}^2 + 2(M+N)(V_{sat}^2 + V_{th}^2)\right)^2}\end{array}}$$

$$D = \frac{4pF^2}{(N+M)(V_{sat}^2 - V_{th}^2)}$$

By way of example Figure 8 shows a timing diagram for this kind of addressing.

Of course the invention is not limited to the embodiments as shown. As mentioned in the introduction the control circuits 18, 19 and/ or the block 25 may impose voltages on the electrodes 2, 3 to make the display vibrate, either or not in the acoustic region (singing display).

Other input functions may be used in stead of touching such as a microphone function

The invention resides in each and every novel characteristic feature and each and every combination of characteristic features. Reference numerals in the claims do not limit their protective scope. Use of the verb "to comprise" and its conjugations does not exclude the presence of elements other than those stated in the claims. Use of the article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements.